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FACTOR PRICE CHANGES, TECHNICAL EFFICIENCY, AND REVENUE REQUIREMENTS REGULATION

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David P. Baron and Raymond R. De Bondt

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I. Introduction

A central problem of public utility regulation is the adjustment of regulatory instruments in response to exogenous changes in the economic environment of a regulated firm. Adjustments in output prices required because of changes in factor prices, for example, typically are made through an administrative rate review proceedings involving data submission by the firm, commission staff evaluation, and public hearings. The criteria and methods used to determine the appropriate level of prices, and particularly the structure of prices, are often imprecise and appear to depend on economic, social welfare, and political considerations. Empirical studies, such as those of Joskow (1972), Hagerman and Ratchford (1978), and Roberts, Maddala, and Enholm (1978), have provided insight into the determinants of the allowed rate of return for utilities, and the models analyzed by Sibley and Bailey (1978) have a similar focus on the difference between a firm's actual return and its target rate of return.

A regulatory authority's focus on the actual and the allowed rates of return gives the firm the opportunity to affect its total return by substituting capital for labor as in the Averch-Johnson (1962)-type models of Bailey and Coleman (1971), Baumol and Klevorick (1970), and Davis (1973). In those models the firm initiates an administrative rate review by substituting capital for labor and thus driving its earned return below its allowed return. The authority then adjusts the output price to bring the earned return to the level of the allowed return. The authority can easily avoid such an incentive to overcapitalize by permitting output prices to be adjusted only when required by exogenous events such as changes in factor prices or shifts in demand. The anticipation of factor price changes and of a subsequent price adjustment, however, provides the firm with an opportunity to influence its post-adjustment profit through its choice of technology. The model considered here represents a regulatory framework in which output price adjustments can be initiated only by factor price changes and not by decisions of the firm.

In response to a factor price increase, a firm will file with the regulatory commission a new tariff effective at a specified date, and the commission will then suspend the tariff pending administrative review. Evaluation of the data supporting the new tariff and public hearings then take place over an extended processing period at the end of which the commission directs the firm to file a new tariff with specified prices that are estimated to yield the allowed rate of return for the firm.

In the context of rate of return regulation, output prices are often set through a "revenue requirements" approach in which prices are determined to provide sufficient revenue to permit the firm to earn the allowed rate of return on its rate base or invested capital. This approach involves estimating the operating costs of the firm and adding to that figure the total allowed return on capital determined by multiplying the approved rate base by the allowed rate of return, with the rate base determined on either an historical or a current "test year" basis.

This paper is concerned with a firm's choice of technology when it anticipates a factor price increase and a subsequent price adjustment based on such a revenue requirements approach. Under the revenue requirements procedure, a factor price increase provides an opportunity for the firm to influence its rate base and the adjusted price through its choice of technology. This opportunity leads the firm to undercapitalize for low allowed rates of return and to overcapitalize for higher allowed rates of return. The regulatory authority may also be able to control to some extent the length of the processing period, and a decrease in that length will accentuate the extent of either undercapitalization or overcapitalization.

An alternative to an administrative rate review procedure is the use of an automatic adjustment mechanism such as the fuel adjustment clauses utilized in the regulation of electric utilities.[1] Baron and De Bondt (1979) analyzed the effect on the choice of technology of a fuel adjustment clause, and the results of that analysis will be contrasted in the final section with the results developed here for the revenue requirements approach.

II. The Model

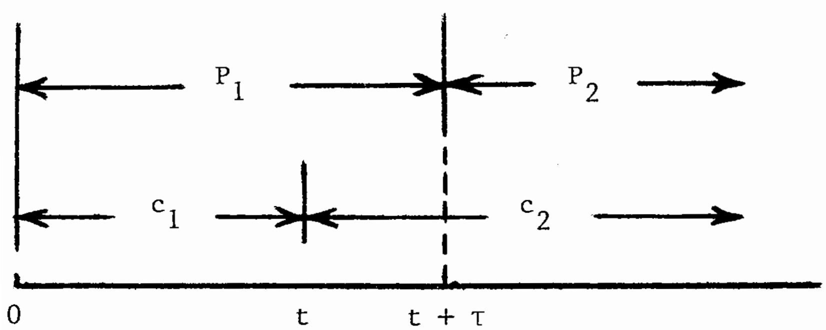
The model utilized is intended to be general enough to capture the principal features of revenue requirements regulation and yet be sufficiently simple to facilitate the analysis of the effects of factor price changes. The focus is on the choice of a fuel-capital ratio in light of an anticipated change in relative factor prices at some uncertain date. Once a factor price has changed, an administrative rate review or hearing is initiated by the regulatory authority or by the firm and a processing period or lag ensues. At the end of the processing period, the price is adjusted according to the revenue requirements approach.

Consistent with the regulatory lag models of Baumol and Klevorick, Bailey and Coleman, and Davis, the initial output price P_1 is assumed to be exogenously given. The firm may, for example, be thought of as a going concern with an existing regulated price P_1 and to have experienced a growth in demand or a depreciation in capital stock that requires the addition of new capacity. The initial factor price of fuel is c_1, and the firm may be thought of as anticipating a relative scarcity of fossil fuels, for example, and hence that the factor price of fuel will increase to a known level c_2 at an uncertain date t in the future.[2] The probability that the factor price has not changed by time t will be assumed to be $(1 - e^{-kt})$, where k is the hazard rate. When the factor price changes the firm initiates a regulatory review and a processing period of known length τ transpires at the end of which a new output P_2 determined by the authority goes into effect.[3] Once the price P_2 is set, it remains in effect thereafter, since the factor price is assumed to remain constant at c_2. The timing aspects of the model and the corresponding notation are summarized in Figure 1.

INSERT FIGURE 1

Figure 1

Time Frame and Notation



The production possibilities of the firm will be represented by a simple putty-clay technology involving two inputs: fuel and capital. At time zero the firm can freely choose its technology, characterized by the fuel-capital ratio γ, but once that ratio has been determined, it cannot be altered.[4] The <u>ex ante</u> production function is specified as homothetic with output Q_i in period i given by $Q_i = H[G(K_i, f_i)]$, where H and G are strictly increasing functions and G is homogeneous of degree one.

The firm is assumed to be required to satisfy demand, and the <u>ex post</u> fuel and capital inputs required to meet demand $Q(P_i)$ are determined by the fuel-capital ratio chosen <u>ex ante</u>. Once the fuel-capital ratio has been determined, the <u>ex post</u> inputs are constrained to lie on a ray in the (K,f)-plane and are given, respectively, by

$$K_i(Q_i,\gamma) = g(\gamma)\phi_i, \quad i = 1,2$$

$$f_i(Q_i,\gamma) = \gamma K_i(Q_i,\gamma) = \gamma g(\gamma)\varphi_i, \quad i = 1,2,$$

where $\phi_i \equiv \phi(Q(P_i))$ is the inverse of H, $Q_i \equiv Q(P_i)$, and $g(\gamma) = 1/G(1,\gamma)$ is strictly decreasing. The profit earned by the firm is then

$$\pi_1 = P_1Q(P_1) - c_1f_1 - vK_1 = P_1Q_1 - \phi_1M_1 \quad \text{for } [0,t)$$

$$\pi_2 = P_1Q_1 - \phi_1M_2 \quad \text{for } [t, t+\tau)$$

$$\pi_3 = P_2Q_2 - \phi_2M_2 \quad \text{for } [t+\tau, \infty)$$

where v is the cost of capital and $M_i = c_i\gamma g(\gamma) + vg(\gamma)$ is the cost per unit of ϕ_i.

The objective of the firm is assumed to be the maximization of expected discounted profits V which, given the assumption of a constant hazard rate k for the time of the factor price change, may be written as

$$V = [r\pi_1 + k(1 - e^{-rr})\,\pi_2 + ke^{-rt}\pi_3]/(r(r + k)),$$

where r is the discount rate.[5] The value of the firm is thus a linear combination of the profits π_1, π_2, and π_3 with the weights depending on the discount rate, the hazard rate k, and the length of the processing period. The value V will be assumed to be strictly concave in γ, the functions π_i, i = 1,2,3, are assumed to be continuously differentiable in γ, and π_3 is assumed to be continuously differentiable in P_2.

The model is completed by specifying how the price P_2 is set in response to the factor price increase. The resulting price increase reduces demand, and hence, the capital in place to satisfy demand at the initial price P_1 is excessive. The cost of that excess capacity must be borne by consumers, by the firm, or shared by both. If the cost is borne by consumers, the price P_2 may be thought of as being set to provide the firm with the allowed return on the total capital $K_1 = \phi(Q(P_1))g(\gamma)$ in place prior to the output price change. In this "historical rate base" revenue requirements approach, the price P_2 is the minimum price P that satisfies

$$PQ(P) - \phi(Q(P))[c_2\gamma g(\gamma) + vg(\gamma)] \geq s\,\phi(Q(P_1))g(\gamma), \qquad (2)$$

where $s \geq 0$ is the allowed (excess) rate of return. If the cost of the excess capacity is borne by the firm, the allowed return is based on the capital stock $K_2 = \phi(Q(P_2))g(\gamma)$ utilized after the price adjustment. The price P_2 in this "current rate base" approach is the smallest price P satisfying

$$PQ(P) - \phi(Q(P))[c_2\gamma g(\gamma) + vg(\gamma)] \geq s\phi(Q(P))g(\gamma). \qquad (3)$$

The constraints in (2) or (3) will be binding at P_2, so these relationships define P_2 as a function of s and γ if such a P_2 will be assumed to exist. Since regulatory policy is public knowledge, the firm will know how price will be adjusted under either the current or the historical rate base approach, and the opportunity created by this adjustment will affect the initial choice of technology. The economic consequences of this incentive problem will first be investigated in the context of the current rate base method, and then the historical rate base method will be discussed.

III. Technical Efficiency with a Current Rate Base Adjustment

A. Technical Efficiency and the Allowed Rate of Return

The regulatory policy of adjusting the output price based on a revenue requirements methodology provides the firm with an opportunity to affect the post-adjustment price through its choice of the fuel-capital ratio. This opportunity would not be present, for example, if the adjusted price were based only on the exogenous factor price c_2 or on the factor price change (c_2-c_1), but the use of an adjustment procedure as in (2) or (3) creates a dependence of price on the choice of technology. The regulatory objective of offsetting the impact of factor price changes on the firm through an adjustment of the output price to achieve the allowed rate of return thus creates an incentive for the firm to choose its fuel-capital ratio in order to maximize its market value V. The fuel-capital ratio $\gamma^* = \gamma^*(s,\tau)$ that maximizes V satisfies

$$\frac{dV}{d\gamma} = -r\phi_1 \frac{\partial M_1}{\partial \gamma} - k((1-e^{-r\tau})\phi_1 + e^{-r\tau}\phi_2)\frac{\partial M_2}{\partial \gamma} + ke^{-r\tau} \frac{\partial \pi_3}{\partial P_2} \frac{dP_2}{d\gamma} = 0. \quad (4)$$

Attention will be restricted to the case in which regulation is effective in maintaining the price P_2 below the monopoly price corresponding to c_2, so that $\partial\pi_3/\partial P_2 > 0$.

To analyze the efficiency of the firm's choice of a fuel-capital ratio, γ^* will be compared with the technically efficient fuel-capital ratio $\gamma^0(P_2)$ that minimizes the discounted expected cost of satisfying the demand corresponding to the prices P_1 and $P_2 = P_2(\gamma^*(s,\tau)$ resulting under revenue-requirements regulation. The efficient fuel-capital ratio $\gamma^0(P_2)$ thus equates the first-two terms in (4) to zero. The direction of technical bias resulting from the price adjustment thus depends on the sign of the last term in (4), so that if the adjusted price P_2 is increasing in γ undercapitalization results, and if P_2 is decreasing in γ, overcapitalization results.

To determine if the adjusted price is increasing or decreasing in γ at the fuel-capital ratio γ^* chosen by the firm when the current rate base approach in (3) is employed, totally differentiate (3) to obtain

$$\frac{dP_2}{d\gamma} = \phi_2\left(\frac{\partial M_2}{\partial \gamma} + sg'\right) / \left(\frac{\partial \pi_3}{\partial P_2} - s\phi_2' \, Q_2' g\right). \qquad (5)$$

Since $s\phi_2'Q_2'\, g$ is negative, the denominator of (5) is positive when regulation is effective. The expression in (5) can be solved for the last term in (4) to obtain

$$\frac{\partial \pi_3}{\partial P_2}\frac{dP_2}{d\gamma} = \phi_2 \frac{\partial M_2}{\partial \gamma} + s\phi_2 g' + s\phi_2' \, Q_2' \, g\frac{dP_2}{d\gamma}. \qquad (6)$$

The first term on the right side is an offset to the post-adjustment period marginal cost represented by the term $(-ke^{-r\tau}\phi_2 \frac{\partial M_2}{\partial \gamma})$ in (4) and provides an incentive to undercapitalize, since the impact of the factor price increase on the choice of technology is eliminated by the price adjustment. The firm thus need bear the full cost of the higher factor price only during the processing lag period, and hence there is an incentive to use more fuel than is technically efficient. The second term in (6) is negative and represents an incentive to substitute capital for fuel in a manner analogous to that in the Averch-Johnson model. The third term represents the effect on the allowed total return of the price change resulting from the choice of the fuel-capital ratio. If the price P_2 is increasing (decreasing) in γ, the effect of γ on P_2 causes the utilized capital $\phi_2 g$ to decrease (increase) which provides an incentive to overcapitalize (undercapitalize).

To determine the nature of the technical bias, let $\gamma_2(s)$ be the fuel-capital ratio that minimizes the post-adjustment "cost" $\phi_2(M_2 + sg)$, so

$$\left(\frac{\partial M_2}{\partial \gamma} + sg'\right)\Big|_{\gamma=\gamma_2(s)} = 0.$$

The function $\gamma_2(s)$ is strictly increasing in s, and the convexity of $(M_2 + sg)$ implies from (5) that undercapitalization (technical efficiency) (overcapitalization) results as $\gamma^* > (=)(<)\ \gamma_2(s)$. The following proposition indicates that for allowed rates of return below a level s^+ undercapitalization results, while higher allowed rates of return can result in overcapitalization.[6]

Proposition 1: There exists a positive allowed rate of return s^+ such that for all lower allowed rates the firm undercapitalizes by choosing a fuel-capital ratio $\gamma^*(s,\tau)$ that is greater than the technically-efficient fuel-capital ratio $\gamma^0(P_2(\gamma^*(s,\tau),s,\tau))$, while for s^+ the firm produces efficiently. If there is no allowed rate of return other than s^+ such that the firm produces efficiently, the firm overcapitalizes for all allowed rates of return in excess of s^+.

The proof is presented in Appendix A.

To interpret this result, first note that the optimal fuel-capital ratio $\gamma^*(s,\tau)$ is decreasing in the allowed rate of return at s=0, since, letting $D \equiv \partial^2 V/\partial^2\gamma$,

$$\frac{d\gamma^*}{ds}\Big|_{s=0} = -\frac{ke^{-r\tau}}{D}\left[\phi_2 g' + \phi_2' Q_2' g\frac{dP_2}{d\gamma}\right]\Big|_{P_2=P_2(\gamma^*(0,\tau),0,\tau)}$$

and $\gamma^*(0,\tau)>\gamma_2(0)$, which together imply that $\partial M_2/\partial\gamma>0$. This implies from (5) that $dP_2/d\gamma>0$, and hence, undercapitalization results for s=0. This undercapitalization is due to the opportunity that the price adjustment resulting from the revenue requirements approach provides to influence the adjusted price P_2 through the choice of the fuel-capital ratio. In choosing its fuel-capital ratio, the firm recognizes that a factor price increase will initiate a price adjustment, and when regulation is effective in maintaining the price below that which the firm would prefer given its choice of technology, the firm prefers to increase its fuel-capital ratio in order to increase the adjusted price P_2.

For a positive allowed rate of return s, the firm has an incentive to increase its rate base, since the post-adjustment profit π_3 is a strictly increasing function of the rate base. The relationship between the fuel-capital ratio, the rate base, and the post-adjustment profit is given by

$$\frac{d\pi_3}{d\gamma} = s\,\frac{dK_2}{d\gamma} = s(\phi_2 g' + \phi_2' Q_2' g \frac{dP_2}{d\gamma}). \qquad (7)$$

The relationship between K_2 and γ given in (7) depends on two effects. First, for a given price P_2 an increase in γ reduces the capital stock by an amount $\phi_2 g'$, which provides an incentive to overcapitalize. Second, the price adjustment required by the choice of γ will increase (decrease) the utilized capital stock as $dP_2/d\gamma<(>)0$. For small values of s, $dP_2/d\gamma$ is positive, so the post-adjustment cost $\phi_2(M_2 + sg)$ is reduced as γ, and the extent of undercapitalization, are reduced. This permits a lower price which results in a larger quantity produced and hence a larger rate base. If $s < s^+$, however, the cost offset resulting from the price adjustment outweighs this incentive to substitute capital for fuel, and undercapitalization results. For larger values of s, decreasing the fuel-capital ratio may result in a higher price and a lower output, but the incentive to increase the rate base by substituting capital for fuel outweighs this effect, so an incentive to overcapitalize is present. If $s > s^+$, this incentive is greater than the cost offset, and overcapitalization results.[7]

In order to illustrate the technical bias that can result from the price adjustment initiated by a factor price change, the technically-efficient fuel-capital ratio will be compared with the fuel-capital ratio γ^* chosen by the firm. The technically efficient fuel-capital ratio γ^0 depends on s only through P_2 and is an increasing function of P_2, since a higher adjusted price reduces the post-adjustment cost $\phi_2 M_2$ relative to the pre-adjustment cost. The adjusted price depends on s both directly and indirectly through the influence on $\gamma^*(s,\tau)$, so

$$\frac{dP_2}{ds} = \frac{\partial P_2}{\partial \gamma} \frac{d\gamma^*(s,\tau)}{ds} + \frac{\partial P_2}{\partial s}. \tag{8}$$

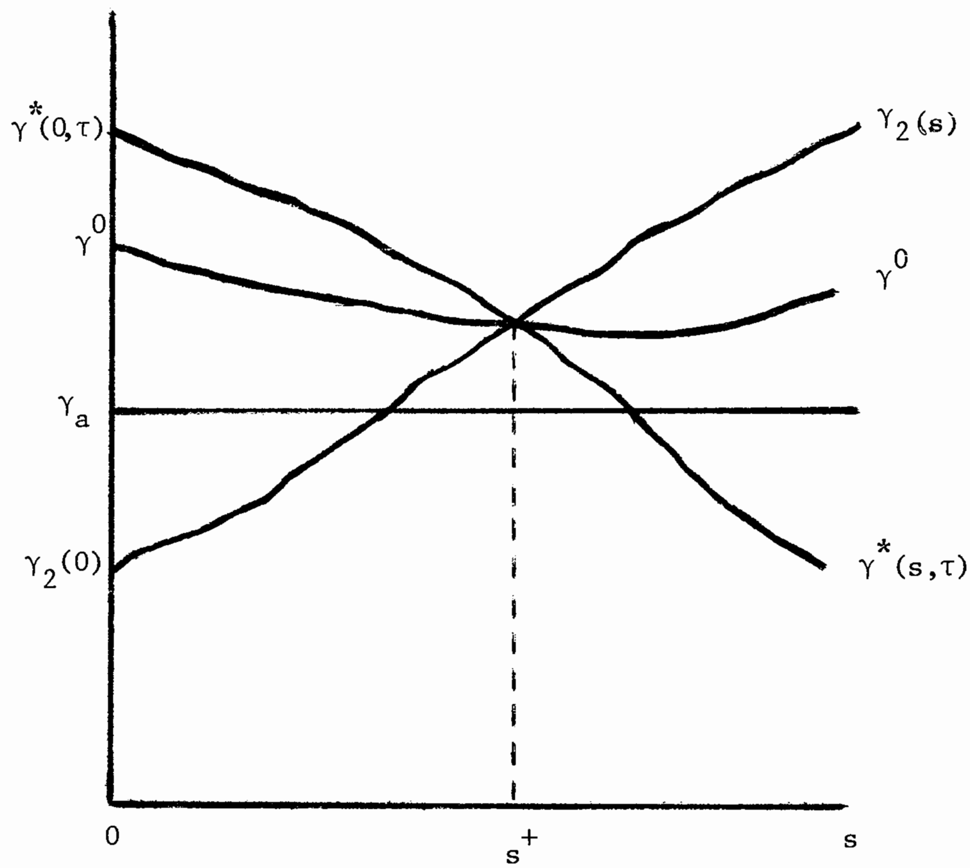
The last term can be evaluated from (3) as

$$\frac{\partial P_2}{\partial s} = \frac{g\phi_2}{\partial \pi_3/\partial P_2 - s\phi_2' \quad Q_2' \, g},$$

which is positive when regulation is effective. The term $\partial P_2/\partial \gamma$ is positive (negative)(zero) as the firm undercapitalizes (overcapitalizes) (produces efficiently), so if γ^* is decreasing in s, the adjusted price in (8) is an increasing function of the allowed rate of return s. Evaluating $d\gamma^*(s,\tau)/ds$ from (4), γ^* is a decreasing function of s if the firm overcapitalizes or produces efficiently, which occurs for $s \leq s^+$ since then $\gamma_2(s) \leq \gamma^*$. Similarly, the technically-efficient fuel-capital ratio γ^0 is decreasing for the same values of s. If the firm undercapitalizes, however, the effect of an increase in s on γ^0 is unclear. Figure 2 illustrates the relationship between $\gamma^*(s,\tau)$ and γ^0.

INSERT FIGURE 2

Figure 2



The undercapitalization that results in this model for $s<s^+$ is in contrast to the overcapitalization that results in the Averch-Johnson type models studied by Bailey and Coleman, Baumol and Klevorick, and Davis. To provide a comparison with these models, consider the case in which there is no factor price change ($c_2 = c_1$), so that the technically efficient fuel-capital ratio γ_1 is that which minimizes the unit cost M_1. Also assume that an administrative rate review can be initiated by the firm through its choice of technology, so that the firm can affect the price P_2 through the choice of γ even though factor prices are known not to change. The effect on P_2 of a change in γ is from (5)

$$\left.\frac{dP_2}{d\gamma}\right|_{c_2 = c_1} = \phi_2\left(\frac{\partial M_1}{\partial \gamma} + sg'\right)/\left(\frac{\partial \pi_3}{\partial P_2} - s\phi_2' Q_2' g\right). \tag{9}$$

At the efficient fuel-capital ratio γ_1, the price P_2 is a decreasing function of the fuel-capital ratio for $s > 0$, since the denominator in (9) is positive when regulation is effective, the term $\partial M_1/\partial\gamma$ is zero at γ_1, and $sg' < 0$. To determine if the firm has an incentive to overcapitalize by choosing a fuel-capital ratio greater than γ_1, the effect of a firm-initiated price change on the value of the firm must be determined. Evaluation yields

$$\left.\frac{dV}{d\gamma}\right|_{\substack{\gamma=\gamma_1 \\ c_2=c_1}} = ske^{-r\tau} \frac{\partial \pi_3}{\partial P_2} \left.\frac{dP_2}{d\gamma}\right|_{\substack{\gamma=\gamma_1 \\ c_2=c_1}},$$

which is negative for $s > 0$, so the firm finds it optimal to overcapitalize.

To relate this result to that in Proposition 1 for the case in which a factor price increase is anticipated, note that a factor price increase results in a technically efficient fuel-capital ratio γ^0 that is lower than the fuel-capital ratio γ_1 that is optimal in (9) when $c_2 = c_1$. Consequently, for a low allowed rate of return ($s < s^+$) the Averch-Johnson incentive to overcapitalize is weak, and the firm chooses too high a fuel-capital ratio in order to realize a greater market value through a higher adjusted price. For a higher allowed rate of return ($s > s^+$) the incentive to overcapitalize is greater, and the firm chooses a fuel-capital ratio lower than that which is technically efficient.

Since the direction of the technical bias that results with a price adjustment under revenue requirements regulation is a function of the allowed rate of return, the regulator can set s to achieve welfare objectives. While no welfare function will be specified here, the Pareto criterion can be used to exclude those allowed rates of return that are dominated by an allowed rate of return that yields both a greater market value for the firm and a lower price for consumers. Since the market value is an increasing function of s, the regulator will increase s if the adjusted price P_2 is decreasing in s as given in (8). The Pareto optimal allowed rates of return are thus those for which $dP_2/ds > 0$. If γ^* is a decreasing function of s as seems reasonable, dP_2/ds is positive if the firm overcapitalizes or produces efficiently and is positive for at least some s that result in undercapitalization. Consequently, no conclusion can be drawn about the nature of the technical bias resulting from the regulator's choice of the allowed rate of return.

B. The Effect of the Length of the Processing Period

The regulatory authority may have some ability to control the length τ of the processing period through either the granting of interim rates or through the conduct of public hearings. Appendix B presents data on the length of the processing lag for those states in which fuel adjustment clauses (FAC's) were not employed and for selected states in which they were. These data suggest that while there are some states such as Illinois where commission orders are generally issued near the statutory limit of eleven months, other states such as Pennsylvania, Michigan and California do show a considerable variation in the length of the processing period. Furthermore, those states not employing FAC's tend to have a shorter processing lag than do states that employ FAC's.

While the length of the processing period has no effect on the direction of the technical bias, it does affect the magnitude, since τ affects the fuel-capital ratio chosen by the firm. The effect of τ on the optimal fuel-capital ratio γ^* is determined by differentiating (4) to obtain

$$\frac{d\gamma^*}{d\tau} = ke^{-r\tau}\,[(\phi_1 - \phi_2)\,\frac{\partial M_2}{\partial \gamma} + \frac{\partial \pi_3}{\partial P_2}\,\frac{dP_2}{d\gamma}]/D. \tag{10}$$

Solving (4) for the numerator and substituting into (10) yields

$$\frac{d\gamma^*}{d\tau} = \phi_1(r\,\frac{\partial M_1}{\partial \gamma} + k\,\frac{\partial M_2}{\partial \gamma})/D. \tag{11}$$

To determine the sign of the numerator in (11), let γ_a be the fuel-capital ratio that minimizes the constant output cost $\phi_1(rM_1 + kM_2)$ that the firm would incur if there were no price adjustment, so $\gamma_a = \gamma^0(P_2)|_{P_2=P_1}$. Then, if the fuel-capital ratio γ^* chosen by the firm is greater (less) than γ_a, the numerator in (11) is positive (negative) and γ^* is decreasing in τ for all $\tau \geq 0$. To determine the relationship between γ^* and γ_a, it is simply necessary to make a comparison for any one value of τ. For example, if $\gamma^*(s,0)$ is greater (less) than γ_a, $\gamma^*(s,\tau)$ is a strictly decreasing (increasing) function of the length of the processing lag. In all cases $\gamma^*(s,\tau)$ approaches γ_a as the length of the processing period increases. These relationships are summarized in the following proposition and are illustrated in Figure 3.

Proposition 2: The optimal fuel-capital ratio γ^* is a decreasing (constant) (increasing) function of the length of the processing lag τ if the optimal fuel-capital ratio $\gamma^*(s,0)$ corresponding to no lag is greater than (equal to) (less than) the fuel-capital ratio γ_a that is optimal if there were no output price adjustment.

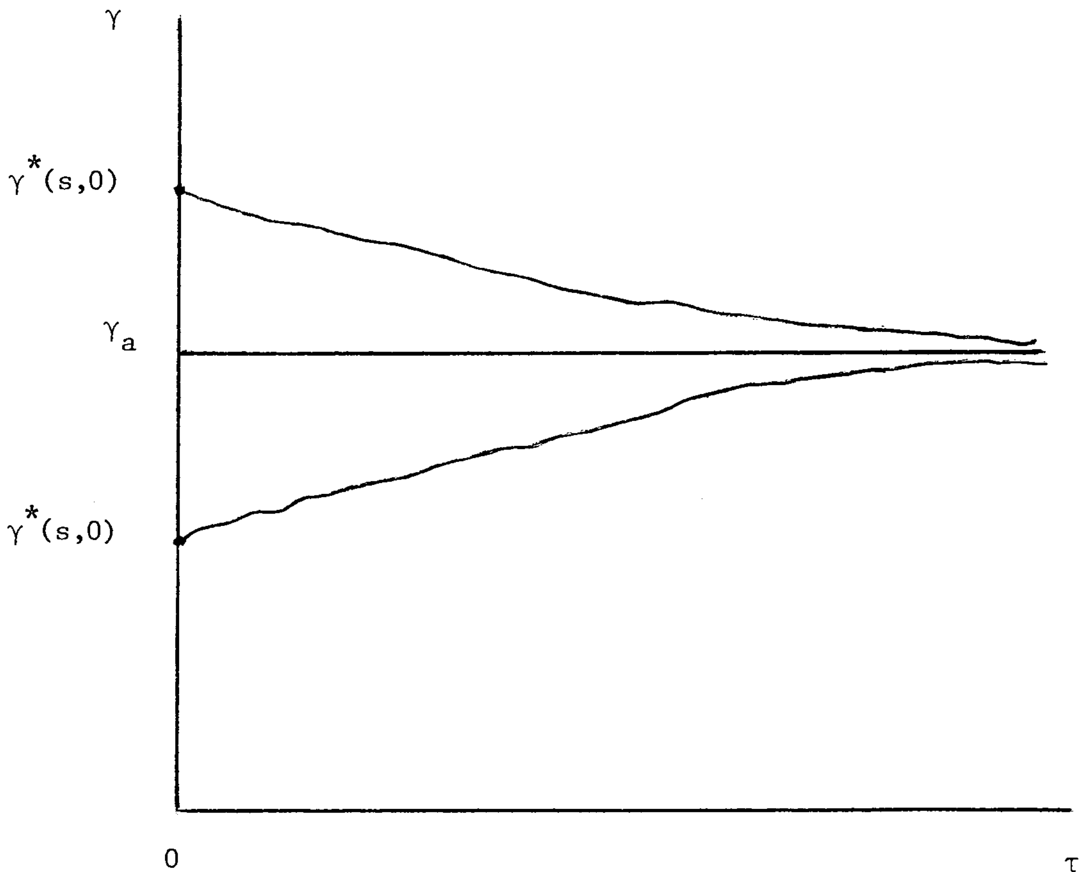
The impact of a lengthening of the processing period on the optimal fuel-capital ratio is a result of two influences represented in (10). First, the firm must satisfy the demand at the price P_1 over a longer period and the demand at P_2 over a shorter period. Second, the incentive to affect the post-adjustment profit π_3 through the choice of the fuel-capital ratio is diminished because of the additional delay in the price adjustment. The first effect acts to decrease (increase) γ^* from (10) as $\partial M_2/\partial\gamma <(>) 0$, while the second effect acts to decrease (increase) γ^* as $dP_2/d\gamma < (>) 0$. For $s < s^+$, $dP_2/d\gamma > 0$ and $\partial M_2/\partial\gamma > 0$, so γ^* is decreasing in the length of the processing period when the firm undercapitalizes. For $s > s^+$, $dP_2/d\gamma < 0$ and if s is sufficiently large that $\gamma^* < \gamma_a$, γ^* can be increasing in τ.

The effect of the length of the processing period on the post-adjustment price is given by

$$\frac{dP_2}{d\tau} = \frac{\partial P_2}{\partial\tau} + \frac{\partial P_2}{\partial\gamma} \cdot \frac{d\gamma^*}{d\tau} = \frac{\partial P_2}{\partial\gamma}\frac{d\gamma^*}{d\tau} ,$$

since P_2 does not depend directly on τ. Consequently, if the firm finds it optimal to undercapitalize, the term $\partial P_2/\partial\gamma$ is positive, and since $d\gamma^*/d\tau$ is negative, when the firm undercapitalizes, the adjusted price

Figure 3



P_2 is reduced by an increase in τ. If the firm overcapitalizes and γ^* is increasing in τ, the same result obtains, but if γ^* is decreasing in τ, P_2 is increasing in τ. The value of the firm is decreasing in τ, since a lengthening of the processing period delays the price adjustment, so a Pareto improvement can only be made when s is set so that the firm overcapitalizes and γ^* is decreasing in τ.

IV. Technical Efficiency With an Historical Rate Base Adjustment

If the regulatory authority were to use an historical rate base, the adjusted price would be calculated on the rate base $\phi_1 g$, which is greater than the post-adjustment, utilized capital stock $\phi_2 g$ whenever $P_2 > P_1$. This results in a greater post-adjustment allowed profit compared to that in the previous section and eliminates the risk to the firm that its earnings would be affected by a factor price change. The effect of a factor price increase on technical efficiency under the historical rate base approach can be analyzed in the same manner as that for the current rate base approach with the difference that the ambiguity shifts from $\gamma^*(s,\tau)$ to $\gamma_2(s)$. With a historical rate base $\gamma^*(s,\tau)$ is unambiguously decreasing in s, since the post-adjustment profit is unaffected by the output price adjustment. The output price adjustment however affects the fuel-capital ratio analogous to $\gamma_2(s)$ that is used to determine the direction of technical bias, and consequently, the effect of s on $\gamma_2(s)$ is ambiguous. If however P_2 is increasing in s, $\gamma_2(s)$ is increasing in s. Then, an s^+ as in Figure 2 exists, and undercapitalization results for $s < s^+$ while overcapitalization results for $s > s^+$. The effect of the length of the processing period on $\gamma^*(s,\tau)$ is as given in Proposition 2, so if the allowed rate of return is such that $\gamma^*(s,0) > (<)\ \gamma_a$, the optimal fuel-capital ratio is decreasing (increasing) in τ.

IV. Conclusions

The revenue requirements approach to rate setting for public utilities adjusts output prices in response to factor price changes in order to achieve an allowed rate of return on either the invested or the utilized capital. Since the firm knows that a factor price change will initiate an administrative rate review, an opportunity is created to manipulate the output price and hence the profit of the firm through the choice of technology. The nature of the technical bias resulting from this incentive depends on the allowed rate of return and the length of the processing lag. At least for small s the post-adjustment profit is increasing in the fuel-capital ratio, and hence, the firm finds it optimal to undercapitalize. As the allowed rate of return is increased, the incentive analogous to that in the Averch-Johnson model to substitute capital for fuel can dominate and result in overcapitalization. Since the post-adjustment profit π_3 is increasing in P_2, a Pareto improvement can be made if P_2 is decreasing in s. Consequently, the allowed rate of return will be set so that the adjusted price is increasing in s.

The regulatory authority may be able to affect the length of the processing period, although the requirements for public hearings and for staff evaluations place a lower bound on the length of the processing lag. The effect of the length of the processing lag on the optimal fuel-capital ratio γ^* depends on the relationship between γ^* and the constant-output technically efficient fuel-capital ratio γ_a. If $\gamma^*(s,\tau) > (=)(<) \gamma_a$, $\gamma^*(s,\tau)$ is a decreasing (constant) (increasing) function of τ. The adjusted price is decreasing in τ if the allowed rate of return is set so that the firm undercapitalizes, but the value of the firm is decreasing in τ, so no Pareto improvement can be made in this case.

The most commonly used alternative to administrative rate review procedures is an automatic adjustment mechanism such as the fuel-adjustment clauses (FAC's) used in electricity pricing. FAC's that are designed to adjust the output price by an amount equal to the change in average cost have been studied by Baron and De Bondt (1979). Such an adjustment has no necessary relationship to the allowed rate of return s that plays an integral role in the model considered here, but FAC's can involve a "collection lag" representing the time interval between the factor price change and the output price adjustment. With a FAC anticipation of a factor price increase results unambiguously in under-capitalization when regulation is effective, since the firm can obtain a higher adjusted price when the factor price of fuel increases by having chosen a technology that uses more fuel relative to capital than is optimal. The firm's optimal fuel-capital ratio is strictly decreasing in the length of the collection lag, so extending the collection lag can reduce, but not eliminate, the technical inefficiency resulting from a FAC. These results stand in contrast to those for the revenue requirements adjustment procedure, since the regulator can choose the allowed rate of return so that overcapitalization results. Furthermore, the firm's optimal fuel-capital ratio can be either an increasing or a decreasing function of the length of the processing period depending on the allowed rate of return set by the regulator. Unfortunately, a welfare comparison between FAC's and revenue requirements procedures for adjusting output prices in response to factor changes is not possible at the level of generality of the model considered here.

The empirical evidence on the technical bias caused by regulation as presented by Baron and Taggart (1977), Boyes (1976), Courville

(1974), Cowing (1978), Peterson (1975), Spann (1974), and Stewart (1979) is all based on data from periods prior to that during which rapid increases in fuel prices would have been anticipated, so those studies provide little evidence about the predictions developed here. The predictions do suggest, however, that empirical work will be difficult since the nature of the technical bias depends on the allowed rate of return used by the regulator. Empirical studies conducted on data from a period in which an increase in the relative price of a factor input would be anticipated thus should incorporate the allowed rate of return directly in the model to be tested. Unfortunately, however, the allowed rate of return should be considered as endogenous to the regulatory process, since the regulator may use it as an instrument to affect the adjusted price and the choice of technology by the firm. The latter choice will also depend on the length of the processing lag, so both the allowed rate of return and the length of the processing lag will have to be measured in an empirical study and both should be viewed as endogenous to the process of regulation.

Appendix A

Proof of Proposition 1

The following Lemma is required.

Lemma: $\gamma^*(s,\tau) < \gamma_1$, where γ_1 minimizes M_1.

Proof: The first order condition in (4) may be written as

$$\frac{dV}{d\gamma} = -r\phi_1 \frac{\partial M_1}{\partial \gamma} - k(1-e^{-r\tau})\,\phi_1 \frac{\partial M_2}{\partial \gamma} + ke^{-r\tau}\frac{d\pi_3}{d\gamma} = 0. \qquad \text{(A-1)}$$

First, it will be shown that at $\gamma^*(s,\tau)$, $\frac{d\pi_3}{d\gamma} \leq 0$ and then that this implies $\left.\frac{\partial M_1}{\partial \gamma}\right|_{\gamma=\gamma^*(s,\tau)} < 0$ so that $\gamma^*(s,\tau) < \gamma_1$. Assume that $\frac{d\pi_3}{d\gamma} \geq 0$. Evaluating yields

$$\frac{d\pi_3}{d\gamma} = \frac{\partial \pi_3}{\partial P_2}\frac{dP_2}{d\gamma} + \frac{\partial \pi_3}{\partial \gamma} = \frac{\partial \pi_3}{\partial P_2}\left(\frac{-\frac{\partial \pi_3}{\partial \gamma} + \phi_2 sg'}{\frac{\partial \pi_3}{\partial P_2} - \phi_2' Q_2' sg}\right) + \frac{\partial \pi_3}{\partial \gamma}$$

$$= \left[-\phi_2' Q_2' sg\frac{\partial \pi_3}{\partial \gamma} + \frac{\partial \pi_3}{\partial P_2}\phi_2 sg'\right] \Big/ \left(\frac{\partial \pi_3}{\partial P_2} - \phi_2' Q_2' sg\right).$$

If $s = 0$, $\frac{d\pi_3}{d\gamma} = 0$, and from (A-1) $\frac{\partial M_1}{\partial \gamma} > 0$, since $\frac{\partial M_1}{\partial \gamma} < \frac{\partial M_2}{\partial \gamma}$.

If $s > 0$, $\frac{d\pi_3}{d\gamma} \geq 0$ implies that $\frac{\partial \pi_3}{\partial \gamma} = -\phi_2 \frac{\partial M_2}{\partial \gamma} > 0$. This imples that $\frac{\partial M_1}{\partial \gamma} < 0$, and hence from (A-1) that $\frac{dV}{d\gamma} > 0$ which contradicts the optimality of $\gamma^*(s,\tau)$, so $\frac{d\pi_3}{d\gamma} < 0$. This implies from (A-1) that

$$-r\phi_1 \frac{\partial M_1}{\partial \gamma} - k(1-e^{-r\tau})\phi_1 \frac{\partial M_2}{\partial \gamma} > 0. \qquad \text{(A-2)}$$

If $\frac{\partial M_1}{\partial \gamma} \geq 0$, then $\frac{\partial M_2}{\partial \gamma} > 0$ which contradicts (A-2). Thus, $\frac{\partial M_1}{\partial \gamma} < 0$, which completes the proof.

Proof of Proposition 1: First, it will be shown that for $s=0$ the fuel-capital ratio $\gamma_2(0)$ that minimizes the post-adjustment cost $\phi_2 g$ is less than the technically efficient fuel-capital ratio $\gamma(P_2(\gamma^*(0,\tau),0,\tau))$ which is less than the optimal $\gamma^*(0,\tau)$. Substituting (6) evaluated at $s=0$ into (4) yields

$$-r\phi_1 \frac{\partial M_1}{\partial\gamma} - k\phi_1 \frac{\partial M_2}{\partial\gamma} = 0, \tag{A-3}$$

which implies that

$$\left.\frac{\partial M_2}{\partial\gamma}\right|_{\gamma=\gamma^*(0,\tau)} > 0 \quad \text{and} \quad \left.\frac{\partial M_1}{\partial\gamma}\right|_{\gamma=\gamma^*(0,\tau)} < 0. \tag{A-4}$$

Using (A-4) in (5) implies that at $s=0$ undercapitalization $(\gamma^*(0,\tau) > \gamma^0(P_2(\gamma^*, 0, \tau)))$ results. Since $\gamma_2(0)$ minimizes M_2, (A-4) implies that the technically efficient fuel-capital ratio is greater than $\gamma_2(0)$.

Since $\gamma^*(0,\tau) > \gamma_2(0)$ and $\gamma^*(s,\tau) < \gamma_1$ for all $s \geq 0$ and the range of $\gamma_2(s)$ is $[\gamma_2(0), \infty)$, there exists at least one $s > 0$ such that $\gamma^*(s, \tau) = \gamma_2(s)$. The definition of $\gamma_2(s)$ implies that $\frac{dP_2}{d\gamma}=0$ at that s and hence that

$$0 \leq s < (=) s^+ \Rightarrow \gamma^*(s,\tau) > (=) \gamma^0(P_2(\gamma^*(s,\tau), s, \tau)).$$

If no other s exists such that $\gamma^*(s,\tau) = \gamma_2(s)$, then

$$s > s^+ \Rightarrow \gamma^*(s,\tau) < \gamma^0(P_2(\gamma^*(s,\tau), s, \tau)).$$

APPENDIX B

Rate Case Decisions for States Without FAC's, 1/1/76-3/31/77

State and Utility	Application Date	Date of Final Order	New Rates Effective	Approximate lag in Month	Interim Rates In Effect
Nevada					
Nevada Power Co.	4/30/76	10/28/76	10/30/76	6	no
Sierra Pacific Power Co.	9/20/76	3/14/77	3/22/77	6	no
Nevada Power Co.	11/7/75	4/14/76	4/20/76	5 1/2	no
Sierra Pacific Power Co.	12/1/75	6/3/76	6/3/76	6	no
Montana					
Montana-Dakota Utilities Co.	4/18/75	11/10/76	12/15/76	7	yes (3/11/76)
Pacific Power & Light Co.	7/10/74	3/3/76	4/1/76	9	no
Oregon					
Portland General Electric Co.	11/26/75	9/1/76	9/3/76	9	no
Pacific Power & Light Co.	2/20/76	12/17/76	12/20/76	10	no
California Pacific Utilities Co.	10/28/75	3/25/76	3/30/76	5	no
Idaho Power Co.	7/22/74	settled in court	1/20/76	-	no
Idaho					
Washington Water Power Co.	2/17/76	11/12/76	1/21/77	11	no
Pacific Power & Light Co.	4/20/76	8/3/76	8/13/76	4	no
Utah Power & Light Co.	9/9/75	4/28/76	5/1/76	8	yes (1/1/76)
Idaho Power Co.	5/30/75	1/14/76	1/28/76	8	no
Wyoming					
Pacific Power & Light Co.	1/5/76	7/16/76	7/27/76	8	no
Utah Power & Light Co.	9/9/75	3/2/76	3/11/76	6	no
Washington					
Pacific Power & Light Co.	3/19/76	12/29/76	1/11/77	10	no
Washington Water Power Co.	2/17/76	12/23/76	1/21/77	11	no
Puget Sound Power & Light Co.	1/2/76	10/8/76	10/9/76	9	no
Utah					
Utah Power & Light Co.	9/5/75	3/4/76	3/5/76	6	yes (2/1/76)
Utah Power & Light Co.	10/30/76	2/28/77	3/1/77	4	no

Source : Edison Electric Institute, Electric Rate Case Decision Data

Rate Case Decisions for Selected States Using FAC's, 1/1/76-3/31/76 and 7/1/76-3/31/77

State and Utility	Application Date	Date of Final Order	New Rates Effective	Approximate lag in Month	Interim Rates In Effect
Illinois					
Iowa-Illinois Gas & Electric	2/20/76	1/17/77	1/18/77	11	no
Central Illinois Light	8/22/75	7/14/76	7/15/76	11	yes (4/29/76)
Central Illinois Public Service	4/28/75	3/24/76	3/25/76	11	no
Union Electric Co.	2/11/75	1/9/76	1/10/76	11	no
New York					
Niagara Mohawk Power	12/19/75	11/16/76	12/1/76	11	no
Consolidated Edison	4/2/75	2/27/76	3/18/76	11.5	no
California					
Pacific Power & Light	4/9/76	3/9/77	4/4/77	12	no
Southern California Edison	6/7/74	12/21/76	1/13/77	30	yes (12/31/75)
Pacific Gas & Electric	2/25/75	8/24/76	8/27/76	18	no
Michigan					
Detroit Edison	4/10/75	3/30/76	3/31/76	12	no
Consumers Power	11/15/74	7/20/76	7/20/76	21	no
Detroit Edison	1/7/75	7/26/76	7/26/76	19	no
Indiana & Michigan Electric	3/22/76	9/17/76	9/18/76	6	no
Wisconsin-Michigan Power	3/20/75	11/5/76	11/6/76	19.5	yes (7/6/76)
Pennsylvania					
Duquense Light	11/27/74	7/13/76	10/1/76	22	yes (1/26 & 10/26/75)
Pennsylvania Power & Light	3/31/75	8/26/76	8/26/76	17	yes (9/13/75 & 4/14/76)
West Penn Power	10/1/74	7/7/76	11/30/74	*	yes (11/30/74)
Pennsylvania Power	5/30/75	1/27/77	5/8/76	*	no
Philadelphia Electric	11/19/75	2/3/77	10/21/76	*	yes (2/6 & 8/5/76)
UGI Corp., Luzerne Electric Div.	1/23/76	1/27/77	1/28/77	12	yes (8/26/76)

* Retroactive collection was allowed.

Source: Edison Electric Institute, Electric Rate Case Decision Data

Footnotes

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1. These clauses are used widely in the U.S. (see U.S. Senate (1976)) and in some European countries as well (Price Commission (1978), Eurostat (1977), De Bondt (1978), and Müller and Vogelsang (1978)).
2. As Nickell (1977, p. 250) states: "The idea here is that firms are often in the position of having a fairly good idea what is going to happen but are rather uncertain when." Uncertainty about the size of the factor price change is treated for fuel adjustment clauses by Baron and De Bondt (1979).
3. Subsequent results are unaltered when the duration of the processing lag is uncertain, or has a certain and an uncertain part, and the probability of a price revision by a date following the factor price change is exponentially distributed. The processing period is assumed to be of known duration in order to simplify the analysis, which may be a good description of the regulatory process in some states such as Illinois where decisions are typically rendered close to the legal maximum of eleven months.
4. If the fuel-capital ratio is perfectly flexible and can be chosen at time $t + \tau$, overcapitalization will result as in the Averch-Johnson model. Perfect flexibility is a strong assumption and is not made here. The possibility of ex post substitution would however diminish the under-capitalization that can result when the fuel-capital ratio cannot be adjusted ex post.
5. If $F(t)$ denotes the probability that the factor price has not changed prior to time t, the conditional probability density function of a

price change at time t, given that it has not changed prior to t, is $k(t) = F'(t)/(1 - F(t))$, which is referred to as the hazard rate in reliability theory. For simplicity it is assumed that the hazard rate $k(t) = k$, a constant, which implies that $F(t) = 1 - \exp(-kt)$. The expected discounted profit is then

$$V = \int_0^\infty F'(t)\left[\int_0^t e^{-rt_o}\pi_1 dt_o + \int_t^{t+\tau} e^{-rt_o}\pi_2 dt_o + \int_{t+\tau}^\infty e^{-rt_o}\pi_3 dt_o\right]dt.$$

Substituting F(t) and integrating yields (1).

6. A point that has not been addressed is the existence of a price P_2 such that the earned returned $\pi_3 = P_2Q_2 - \phi_2M_2$ equals the allowed return $sg\phi_2$ when $s = s^+$. This requires that

$$(P_2Q_2 - \phi_2M_2)\Big|_{\substack{P_2 = P_2(\gamma^*(s^+,\,\tau),\, s^+,\tau) \\ \gamma = \gamma^*(s^+,\tau)}} \geq s^+g\phi_2\Big|_{\substack{P_2 = P_2(\gamma^*(s^+,\tau),s^+,\tau) \\ \gamma = \gamma^*(s^+,\tau)}}$$

Such a price will be assumed to exist.

7. Although intuition suggests that the fuel-capital ratio γ^* chosen by the firm will decrease as s is increased, a proof of this conjecture is not apparant.

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